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POSSIBILITIES TO STUDY THE MIXING STATE AND ENERGY DISSIPATION IN METALLURGICAL REACTORS USING A SYSTEM BASED ON COLOURED LIQUIDS

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ABSTRACT

Coloured liquids are used to show the stream lines in aqueous systems used as model liquids, in different chemical reactors, also in metallurgical reactors dedicated to liquid steel processing; ladles represent a class where these principles could be succesful applied .

A blue ink was selected as colouring agent because of the low price, good biological tolerability in contact with the human skin and absence of the necessity to treat the used evacuated water .

As modeling liquid for stee was selected freshly distilled waterl.

Mixing energy dissipation was measured at adequate scales using the transmittance and the absorbance of liquid sampleswith two laboratory spectrocolorimeters (KFK-2 Russia and Spekol-10 Carl Zeiss Jena, Germany). Volumic relative concentrations of the coloured liquids starting with 0,0005%vol. and even bellow are measured using this technique and the mentioned devices.

Two model vessels, representing two types of metallurgical reactors, were usd in the present set of experiments. The experimental systems provide enough precise data because of using an adequate and accesible system of image recording and capture, based on a performant commercial web video camera.

KEYWORDS: colouring agent, transmittance T(%), ladle reactor.

1. General aspects

There are many reasons to insist on the physical measurements in mixing phenomena research, generally in liquid, also in liquid alloys.

Firstly, the physical properties of the liquids are not of the same values in the different regions of the mixing reactors, even in the absence of any mixing action. Only especially insulated reactors are isolated and it can be supposed that the liquid contained in the reactor can, reach every moment a perfect equilibrium, the condition of absence of any external or internal perturbation. Ladle reactors are frequently either open, either covered, but the most frequently they are exposed to the normal temperature of the environment. Every time, in this situation it will be a convection movement in the ladle because of the differences between temperatures of the steel, from a central region and the wall region. Even at high values of mixing energy input there are important decreasing of the flow rates toward the walls of the ladle.

Because of a lot of simplifications of the physical reality, sometimes mathematical models are less performant and precise. These simplifications are introduced under the form of the initial imposed conditions and frequently are due to the steady state diffusion coefficients of different species which are considered valid in turbulent conditions; such situations are as it follows:

- in tranzitoric regimes, from zero mixing energy dissipation (recipient in thermal equilibrium with the environment) up to the point when the flow pattern, for a selected plug and a fixed rate of bubbling gas, reaches the next stage –the permanent mixing regime;
- permanent mixing regime – the mixing regime obtained using a selected and well specificated pieces, modellind the porous plug, and an input of bubbling gas rate.

In this moment, a huge amount of research work is done in the field of investigating new methods to improve the predicting performance of the different models, using new experimental techniques and sensors.

The reason for a such attitude is a consequence of the fact that simply mathematical models based on conservation of quantum and energy are too general and use values of the physical, physico-chemical and thermodynamical properties of fluids, which are not quite corresponding to the reality.

Non homogeneity at macro and micro scale is the responsible for all these non-conformities of the models describing mixing phenomena and the adiacent engineering processes in industrial vessels.

A short inventory of the identified tendencies in the study of the mentioned problems shows that mixing is an actual problem in research even in well studied systems; these directions of research uses techniques as it follows:

- reactive tracers to probe macro mixing and macro-segregation in stirred vessels at plant scale [2].
- addition position of a tracer in agitated vessels influences the mixing time obtained by simulation [6].
- special and particular effects are used to study and to perform measurements during mixing in different conditions. Fluorescence is used in study of circular impinging jets [3], and a new reaction pair is used for micromixing study in gaz-liquid systems with large vapour generation [5].
- electrical resistance tomography (ERT) of the agitated vessels is used to perform measurements of mixing gas-liquid [1], as state or associated with visualised reactive tracers technique [4]. In this respect, a novel electrical sensor for monitoring the phase distribution in industrial reactors, was developed [7].

As it results a single technique or procedure to mark the mixing aspects in a qualitative manner is unsatisfactory or incomplete.

Chemical reactions based on gas-vapor generation or precipitated coloured and dispersed phases, associated with sudden changing of properties and colour are used as tracers, markers or devices to visualise the direct effects or associated effects [2] – [5] [8].

In the paper [8] color changes are used in diagnostic of mixing time by visualization of liquid(red) –liquid(blue) mixing processes which produce a yellow liquid; an adjacent indicator(the pH of the instant solution) is used for mixing time, resulting a dual indicator system.

2.Colour as principal indicator of mixing state and energy dissipation

Study of the colour in solutions, as transmittance of the collected small volumes from stirred modelling liquid in the reactor vessel is a measure of the characteristics of the mixing process from the point of view of the following point of views:

- intensity of energy dissipation ε/unit mass, or ε’/unit time;
- uniformity of the dissipation of mixing energy and the special distribution by the liquid low, macro and local distribution;
- time of perfect or partially agreed degrees of mixing, in reactors.

There are many reasons to use colour as indicator of mixing degree and associated sensitive quantities. In order to be understood, values as figures, obtained by simulations and numerical analysis must be shown and positioned in space. Human being is a senzitive one and needs to see a general image in order to compare.

An agglomeration of numbers only rarely is able to promote a fast understanding of the represented phenomena or process evolutions.This is a reason for which, in electric resistance tomography used to model mixing phenomena, as mentioned before, data representing and showing the macro and micro-segregation in mixing under different conditions, in stirred vessels are represented in terms of colours, varying as intensity and changing gradually. Because of the fact that at the end of all this attempts and techniques there is a sensation = colour and a perception of this, using difference, it is normal to take into account the colour and its dissipation in liquid as a measure of different mixing aspects. The main problem in measuring colour of liquid is to do this in a non invasive and non-perturbative manner.When measuring mixing aspects in stirred vessels with segregated region and short-circuits, in permanent established regime, this problem is almost satisfactory solved.

Despite all these difficulties, a kind of tomographic map of mixing could be obtained although using direct measuring of an adequate indicator of the colour intensity. Under the aspects of the quantity of necessary samples in measurements there are devices using enough small amounts to be considered as non-perturbative for the general and local pattern flow.

Using cuvettes of adequate length of the optical path, small liquid samples must be collected rapidly (within less 1 second) while to measure a conductance or a specific resistance around a point is a more complicated procedure.

In the same time, a collected sample is a physical evident probe at the disposition of the researchers a long period of time with adequate conservation precautions. If the colored liquid has an enough long time of stability, there are not problems.

Sets of colored liquids can be analyzed how many times is necessary, without to repeat the whole experiment. If the coloring action of an agent is enough strong, low concentrations are necessary and they are comparable with the concentrations of different elements in steels.

3. Technique and experimental conditions

Initial experiments which were performed have pointed that the analysis of colour in mixed vessels is sensible starting with concentration of 50 µl/l or the equivalent concentration 0,005% vol. Working carefully, the concentration could be decreased with an order of magnitude and so it could be referred to the concentrations of microalloying elements in HSLA steels. As colouring agent named in this paper colour marker and ink it was selected and used a commercial quality blue bright ink Pelikan®, usually used for pens. This ink has no adverse effects in using, handling even when swalling and as a joke, it was found on the net, that despite of this, this ink it is not quite exactly recommended to be used as an aliment. This has permitted us to do experiments without to agress the environment, without any risk for persons involved in experiments and whithout costs and operations for depollution. The modelling liquid was freshly distilled water which provide a good behaviour as stability and sensitivity for blue coloured solutions even at very low dilutions. The rate of decreassing the transmittance of the solutions in the range of low additions of blue marker ink was experimentally established at the value of 6,4 +/_0,2 (%)/ml ink, for the range of aditions representing 0,01-0,1%vol. The range +/_0,2% is due to the imprecision in exact dividing of a the base unit of 1ml blue marker ink. To measure the transmittance of solutions was used an electric photocolorimeter of concentration KFK-2 (Russia, Bashkortostan)(fig.1) at the length of 490nm, in the blue region of the light spectrum, where it was obserwed the maximum value of absorbance and consequently the minimum value of the transmittance in the whole range of working concentrations.

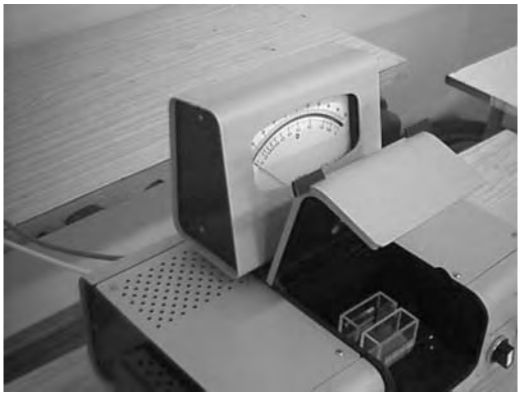

Fig. 1. General image of the electric photocolorimeter KFK – 2, including the chamber of measuring and etalon cuvettes, in working position.

This device presents the possibility to analyse transmittance of liquid colored solutions using also cuvettes of 100mm length, that means an increasing of the sensitivity starting with volumic concentrations of 0,0005%vol. Cuvettes of optical glass presenting an active length 50,0100mm, one for the etalon distilled water the other for the studied solution were used (fig.3). A Carl Zeiss Jena Spekol 10 using the module EK5 for cuvettes of 5cm length was also a solution to be used because it ask only 5ml liquid for analysis (fig.2).

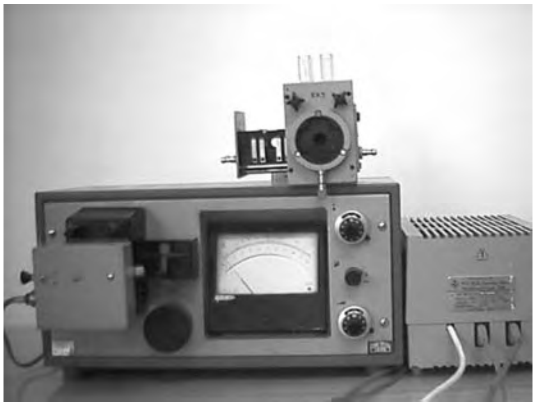

Fig. 2. General image of the spectrocolorimeter SPECOL 10 containing properly named device with measuring device EK1 and electric suppling source. Upper positioned is the measuring device EK5.

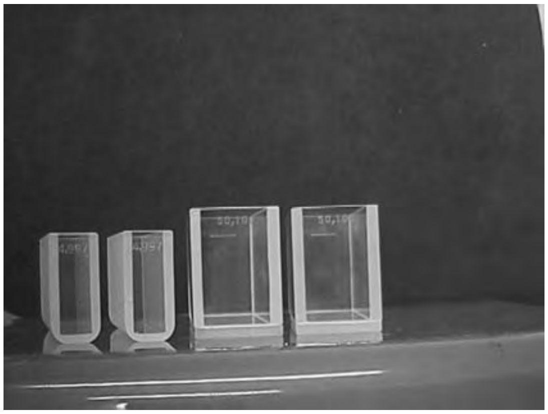

Fig. 3. Pairs of cuvettes of 50 mm optical path used in transmittance measurements based on KFK2 electric photocolorimeter (right positioned pair) and on SPECOL 10/EK5 (left positioned pair). Optical path or capacity of cuvettes may be read directly in the image.

The experimental trials were performed in two laboratory vessels. The first one is a paralelipipedic perspex vessel of dimensions

H=250mm (experimentally used 186mm), L=176mm (front view), T=102mm (thickness) as it can be seen in the fig.4-10.

Fig. 4. *t = 0 s*

Fig. 5*.* *t = 1 s*

Fig. 6. *t = 12 s*

Fig. 7. *t = 46 s*

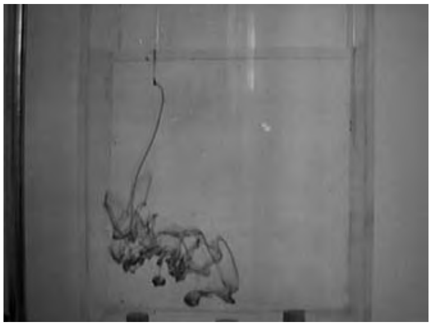

Fig. 8. *t = 52 s*

Fig. 9. *t = 60 s*

Fig. 10. *t = 70 s*

Fig. 11*.* *t = 74 s*

In the fig.13-16 is presented the second vessel, having inner height H=250mm and the inner diameter D=210mm. In the same figures are presented other experimental data regarding the experimental conditions.

Up to this moment all presented data are totally dedicated to the establishing of some experimental limits in the range of the low and very low concentrations of the blue marker ink in distilled water and of the used deviced to produce mixing in experimental conditions similar to some real metallurgical reactors as tundish and ladle, in condition of stirring induced by different devices.

All data regarding images of stirring in both model reactors were recorded using a performant web camera, of commercial quality, provided with the necessary softwear for all necessary image processing.

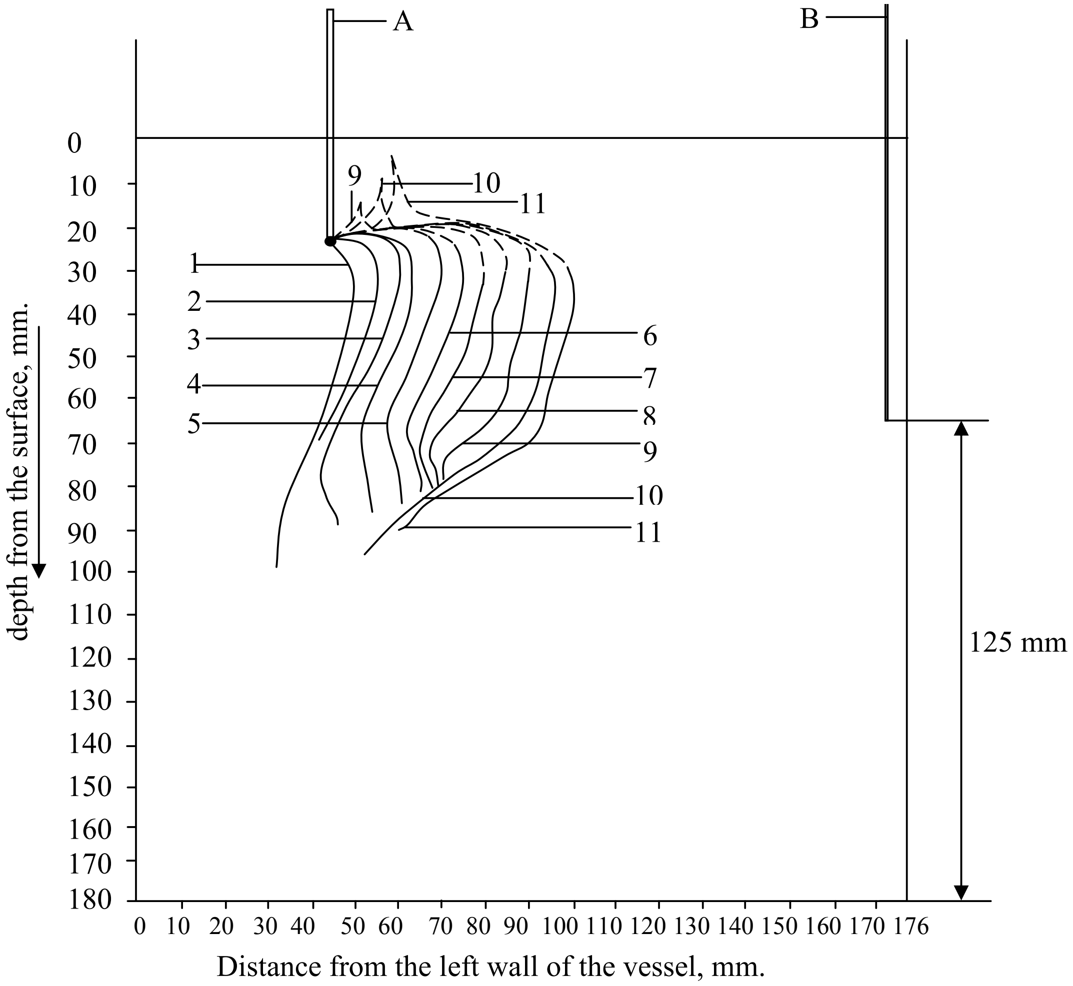

Fig.12. *The evolution of the marker ink stream line under the circulation induced by the injection of 20 ml distilled water in 5 seconds.*
Curves (1 – 12) correspond to an image captured at an established moment (t , seconds).
(1 – 52 s, Fig. 8 ; 2 – 54 s ; 3 –56 s; 4 – 58 s; 5 – 60 s, Fig. 9; 6 – 62 s; 7 – 64 s;
8 – 66 s; 9 – 68 s; 10 – 70 s, Fig. 10; 11 – 72 s)
A – injection needle marker ink (blue);
B – injection needle 20 ml distilled water.

Fig. 13 *Water model vessel.*
Dimensions and data.
Inner height Hi = 250 mm
Inner diameter Di = 210 mm.
Diameter of the bubling nozzle 0,8 mm.
Water column height 220 mm (for ascendent bubling by nozzle).
Precision thermometer 0 – 50°C (±1°C)
Possibilities to use bubling by vertical lance.

Fig. 14. *Bubling by nozzle.*
Air pressure 2.105 N/m2.
Before colour marker ink (t = 0 s).
Reference value of transmittance for distiled water T = 100 %.

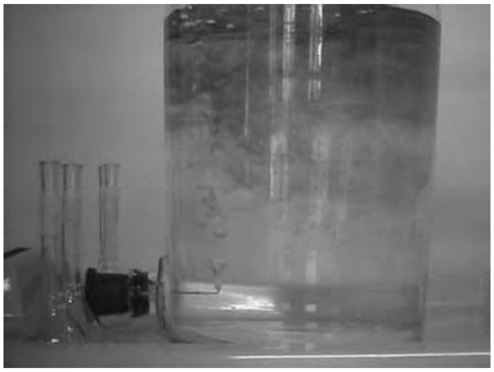

Fig. 15. *Bubling by nozzle.*
Air pressure 2.105 N/m2.
30 seconds after smooth injection of 4 ml marker ink. (t = 5 s).
Value of transmittance for liquid in the central region T = 98,5 %.

Fig. 16. *Bubling by nozzle.*
Air pressure 2.105 N/m2.
60 seconds after smooth injection of 4 ml marker ink.
Value of transmittance for liquid in the central region T = 98,2 %.

4. Experimental results and visualisation of the mixing process

In the fig.4-fig.10 an imagistic analysis is done regarding the initial stability and the dispersion of a thin stream of blue marker ink formed at the orifice of a calibrated tube 0f 1,00 mm inner diameter. The realised experimental system has provided results as it was programmed. So, as it was expected, it can be seen in the fig.10 the small quantum to introduce a small amount of blue marker ink did not a deviation fron the strait vertical line. An impulse produced by the injection of 20ml water had produced a deviation evoluting according to the fig.12. It is very inportant that the visual recording using a common, but of good quality web camera, provided a succesion on the liquid circulation in the upper region of the rectangular vessel.

Trials on the water model of the bubble argon stirred ladle proved that, despite the intesity of mixing, the colour in the vessel is stongly segregated in the first minute and only at the end of the second minute of mixing there is a fast tendency to the complete homogenisation. Mesurement were performed in a singe point at it resulted the necessity to analyse also the evolution of the colour concentration in other points at different levels.

The position of the active extremity of the tube for gaseous phase introduction , also that of the colour introduction is extremely important for the morphology og the mixing zones and require a detailed schedule of trials and mesurements.

Also using this technique , data must be completed and compared with mixing predictions based on macroscopic models for stirred ladles[9].

5. Commentaries and conclusions

Colored liquid technique, recommended by many researchers of the mixing processes also can be used in mixing processes researches based on water models of the metallurgical reactors.

The proposed method in this paper consists in measuring essential and quatitative aspects of mixing by measuring transmittance T(%) of the colored solution sample collected at an established moment.

A such determination is representative for the physical state of mixing in the established region only if the sample is carefully collected, in order to avoid any perturbation of the induced pattern of flow and mixing.

The method is sensitive when studying mixing phenomena and rates in the range of very low concentrations, being useful for study of the elements homogenisation in low alloyed steels (HSLA).

The technique is non-poluting and non-toxic for human health; neutralisation of the persistent colour can easly done using drinking water of common quality.

The developped system of research composed from working liquid, colour marker, device and method to measure the transmittance , vessels representing the metallurgical reactors at scale, and opto-electronic system, based on web camera are adequate to study more complex mixing phenomena.The influence of the way, speed and place where alloying elements are introduced and modes of dissipation of mixing energy are some of them.

Our team offers all cooperation for enlarged groups of researches in Romania and abroad.

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